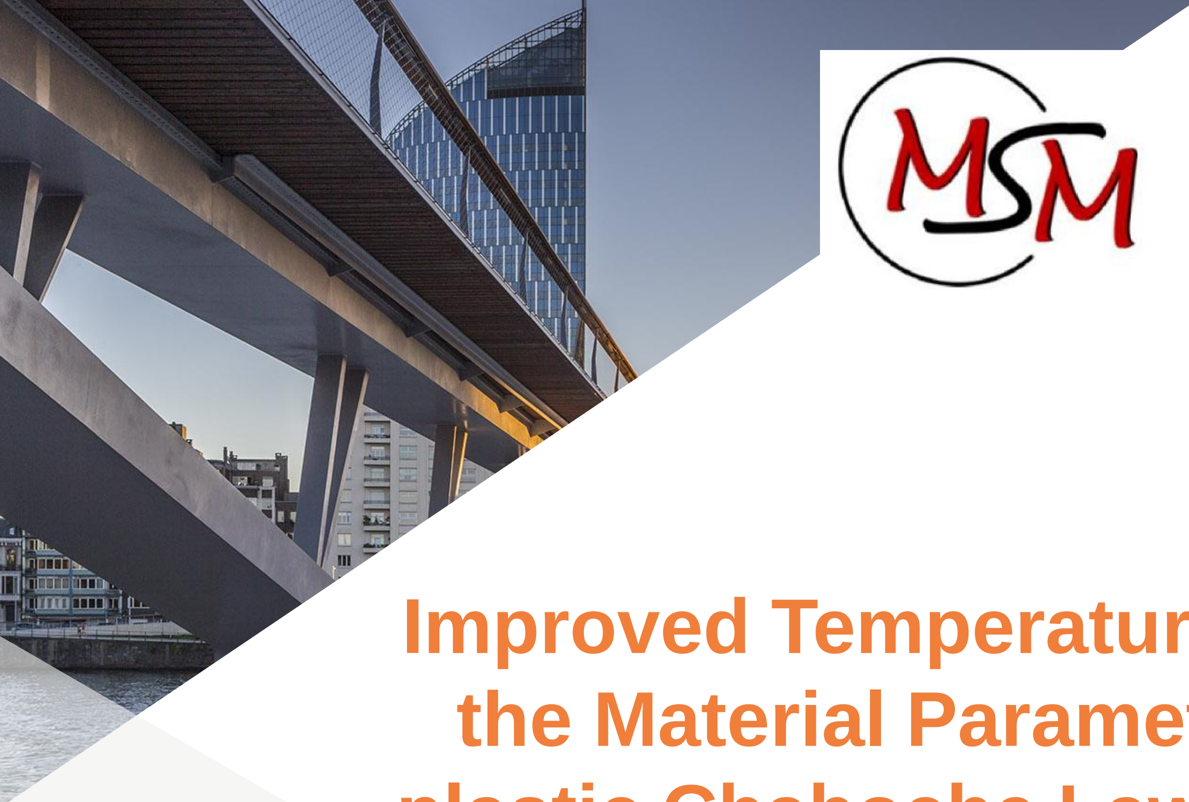


Improved Temperature Dependence of the Material Parameters in a Visco-plastic Chaboche Law for an Accurate Cyclic Hardening Modelling

Laurent Duchêne, Hélène Morch, Anne Marie Habraken

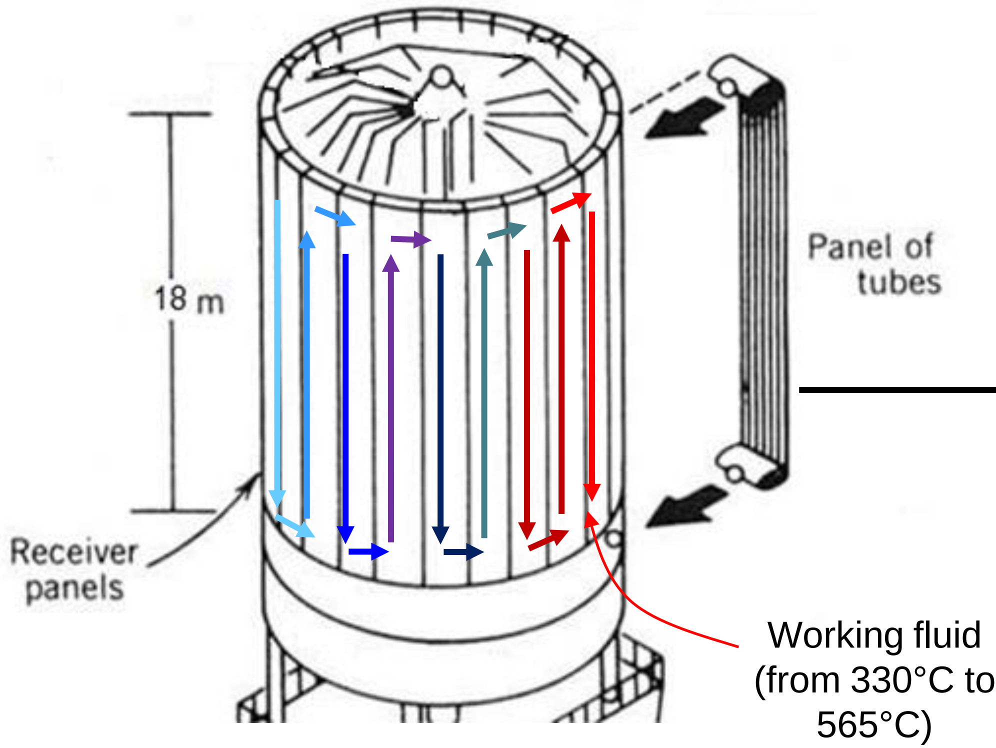
UEE
Urban & Environmental Engineering

Context: Solar power plant

Solar receivers: extreme thermo-mechanical conditions

Khi Solar One power plant (South Africa)

Context: Solar receiver



Solar receiver

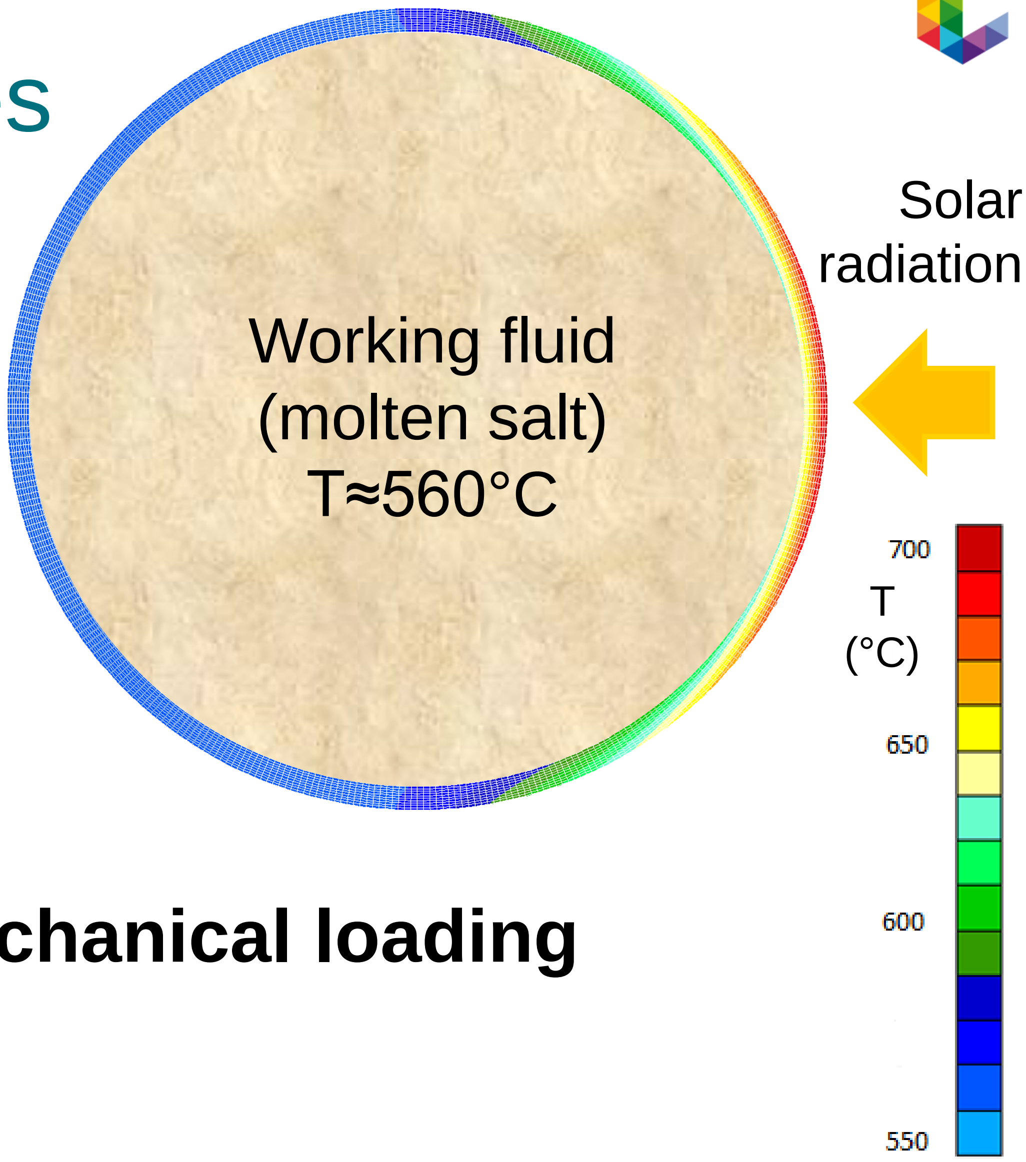
(source : W.B.Stine, R.W.Harrigan, Solar Energy Systems Design)

Tube:
Ø 50 mm
t=1.5 mm

Panel of tubes manufactured from nickel alloy sheet (Haynes 230)

(source : CMI Solar)

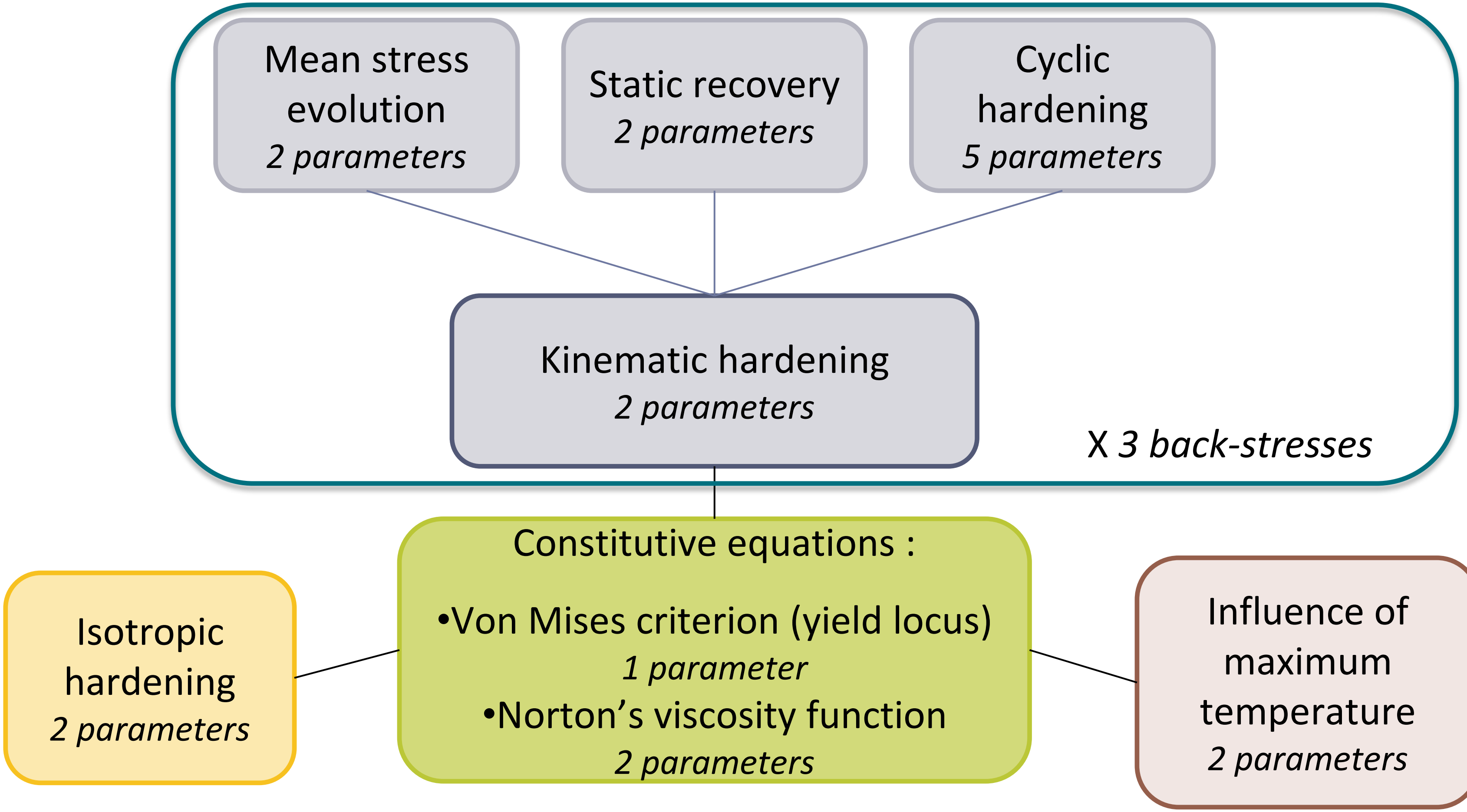
Context: The tubes



Temperature distribution in a tube
(Lagamine FE code)

- **Fatigue + creep**
- **Extreme Thermo-mechanical loading** (Haynes 230)
- **Advanced model**

Advanced Chaboche model



→ 40 parameters

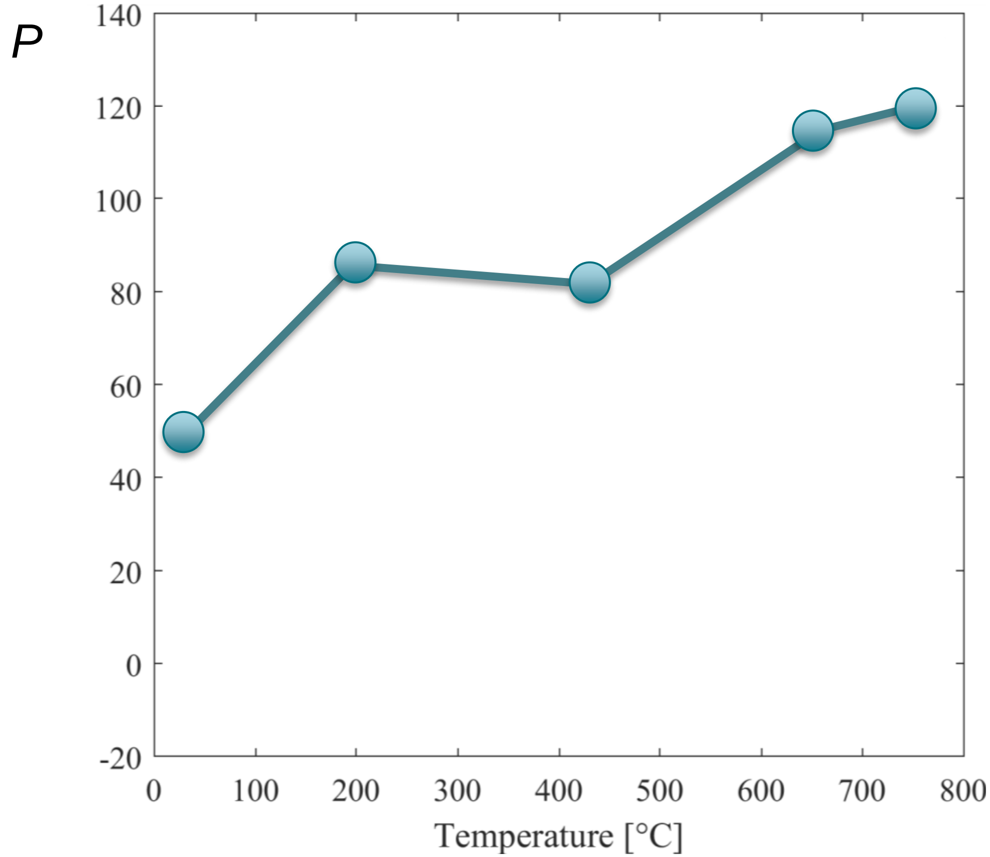
Parameter identification

- From isothermal experimental tests
- Validation on anisothermal tests
- Significant number of parameters:
  - Uniqueness of the solution not guaranteed
  - Physics-based manual identification
    + Optimization algorithm

Temperature dependence

1st method: multi-linear

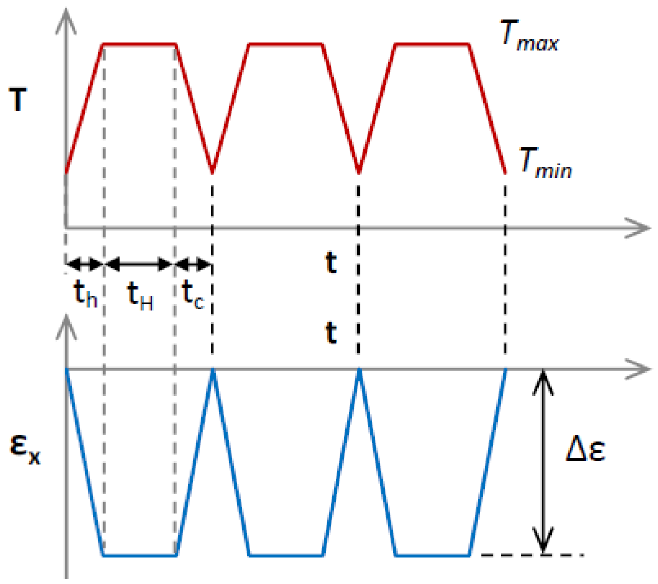
One set of parameters at each test t°:

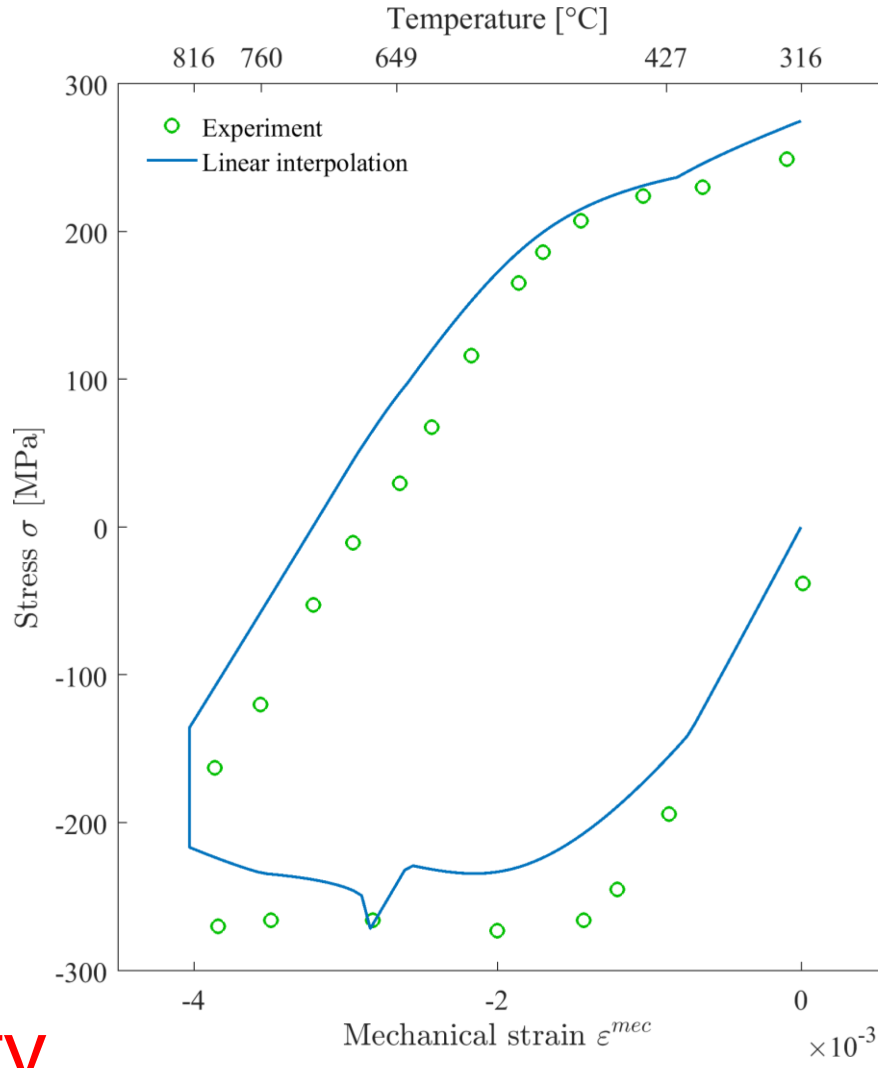


→ 40 x $n_{t°}$ parameters (=200)

Temperature dependence

1st method: multi-linear





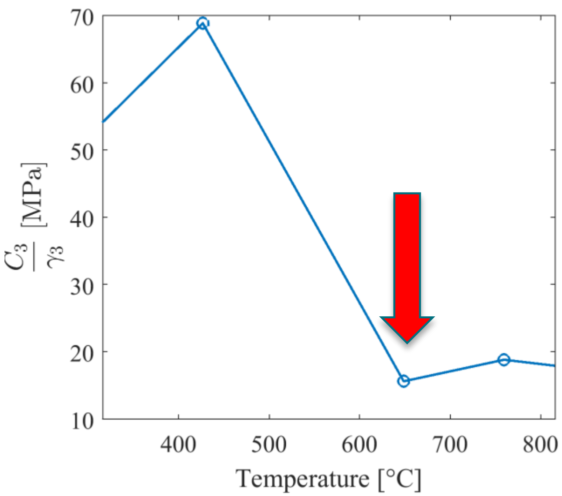
Problem: lack of continuity

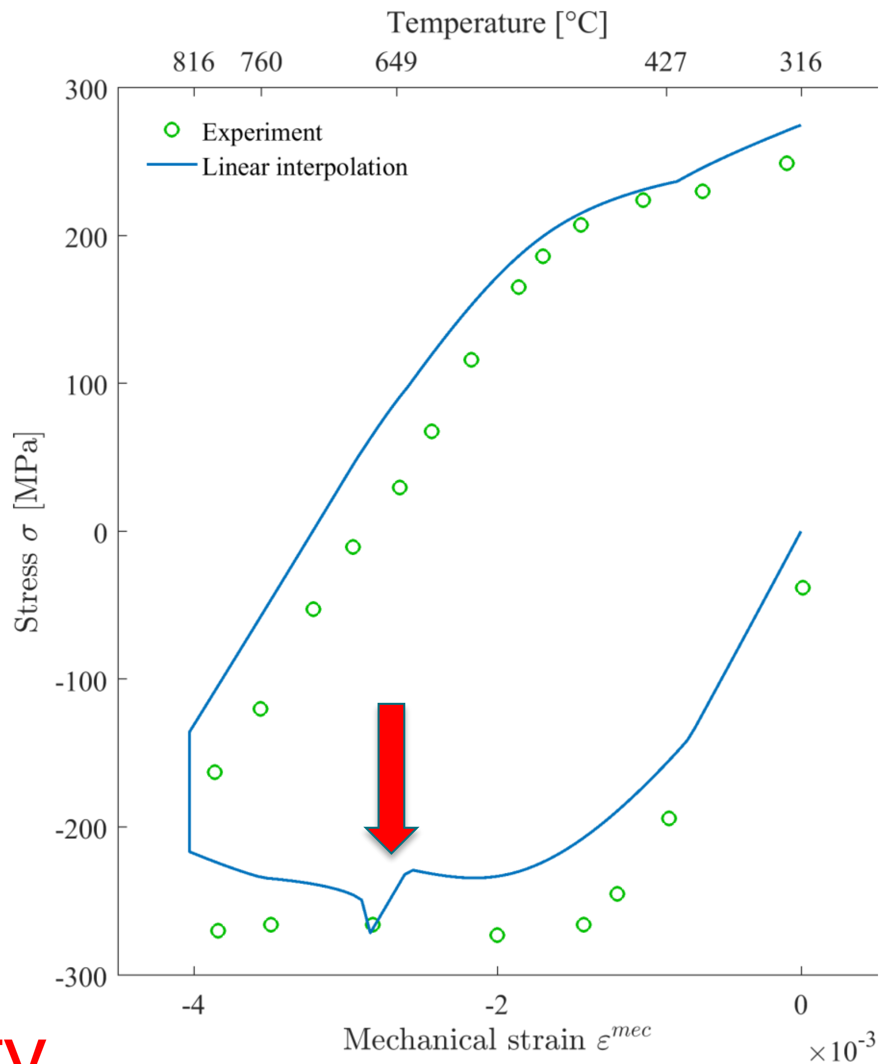
Temperature dependence

1st method: multi-linear

Kinematic hardening

$$\dot{\hat{\underline{X}}}_i = \frac{2}{3} C_i \dot{\underline{\varepsilon}}^{vp} - \gamma_i (\hat{\underline{X}}_i - Y_i) \dot{p}$$





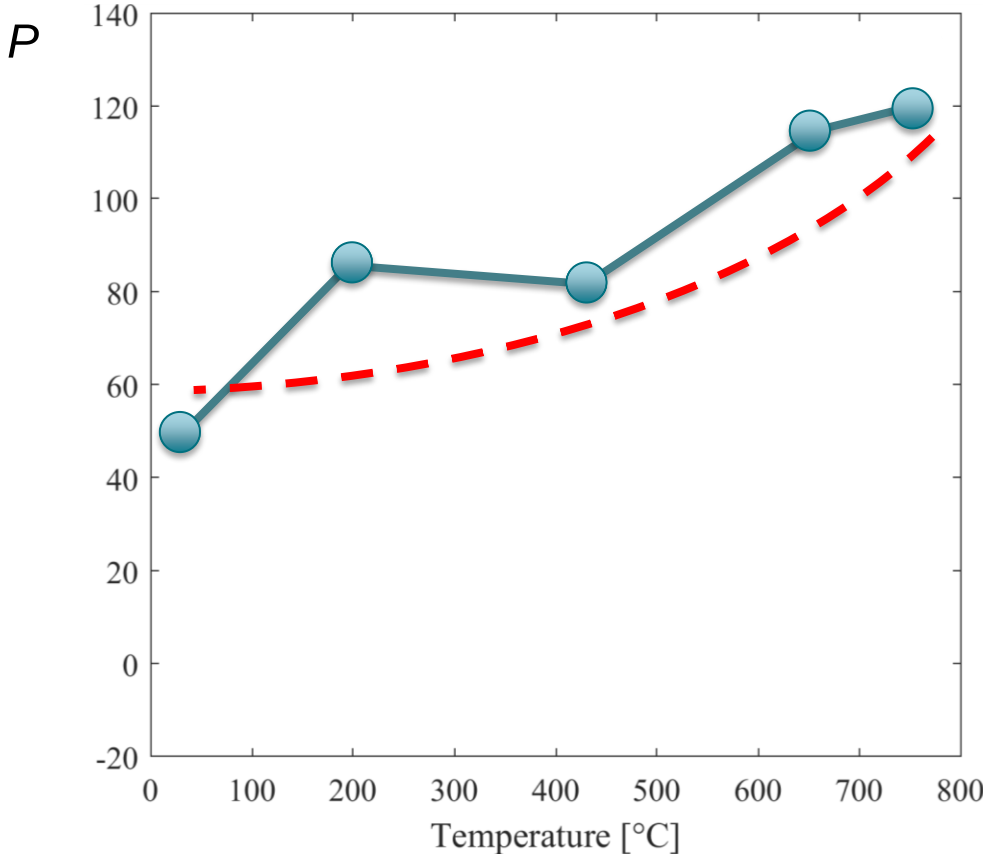
Problem: lack of continuity

Temperature dependence

2nd method: Exponential

$$P = A_P\left(1 - B_p \exp\left(\frac{T}{C_P}\right)\right)$$

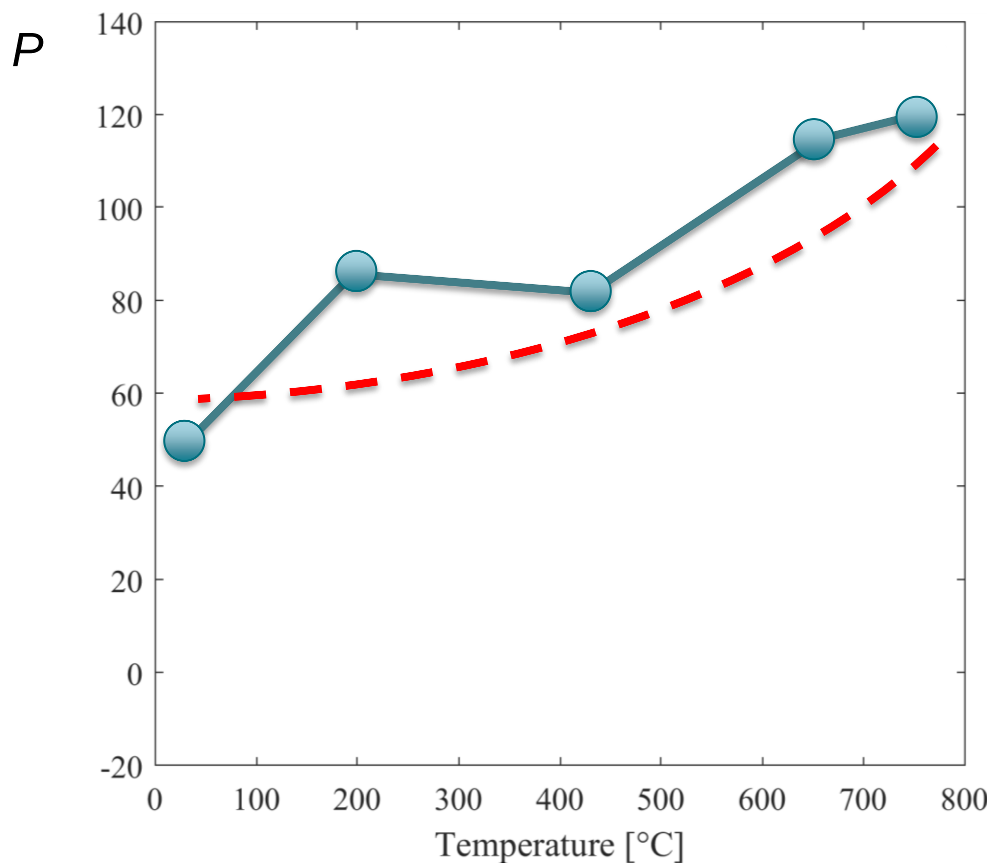
E. Hosseini, S. R. Holdsworth, I. Kühn, and E. Mazza, *Mater. High Temp.*, vol. 32, no. 4, pp. 404–411, 2015.

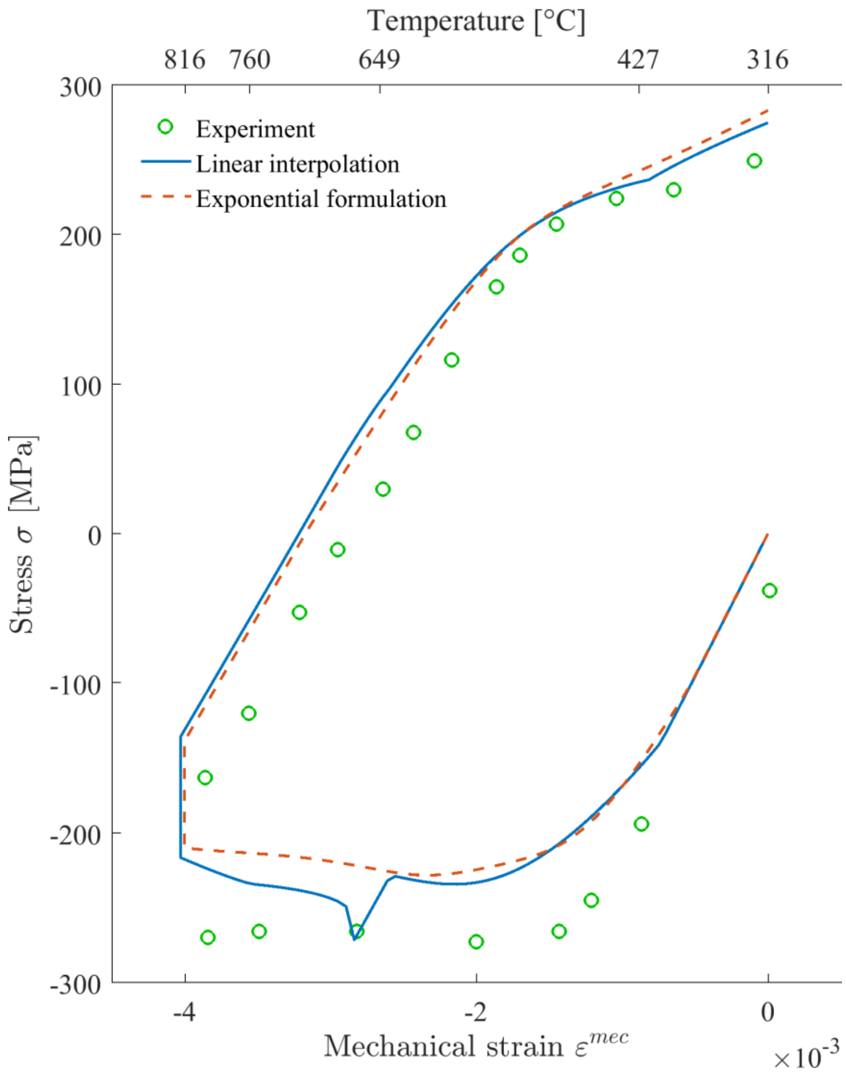


→ 40 x 3 parameters (=120)

Temperature dependence

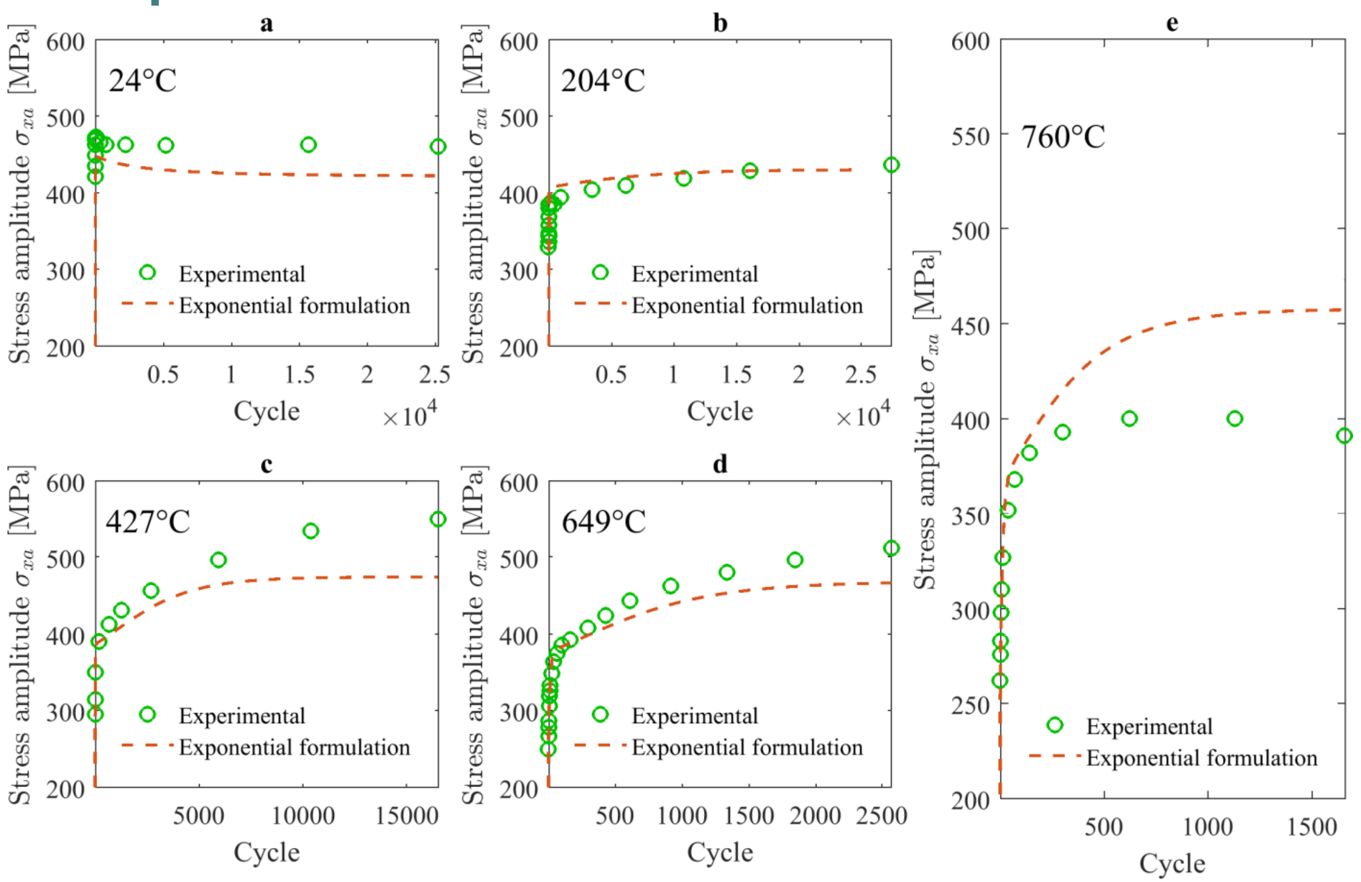
2nd method: Exponential





Temperature dependence

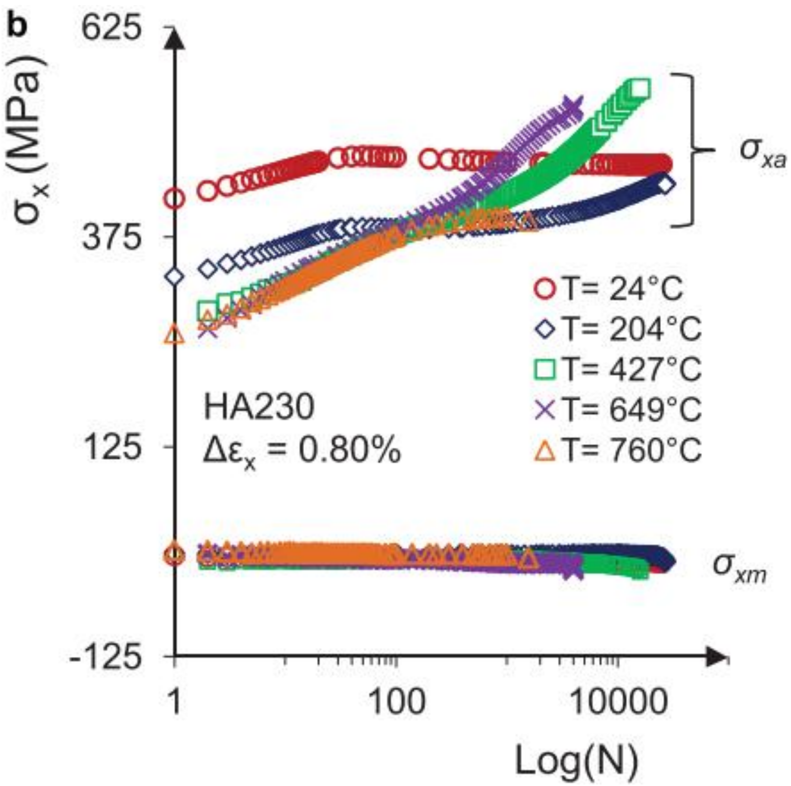
2nd method: Exponential



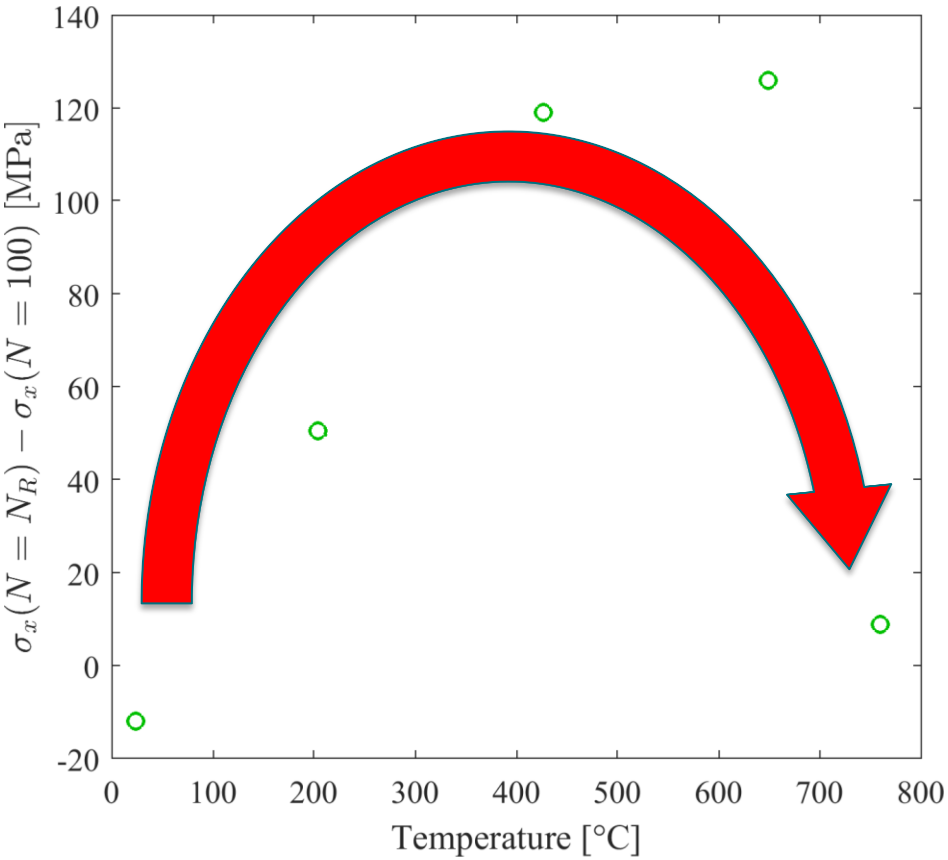
Problem: poor accuracy of the cyclic hardening

Temperature dependence

2nd method: Exponential



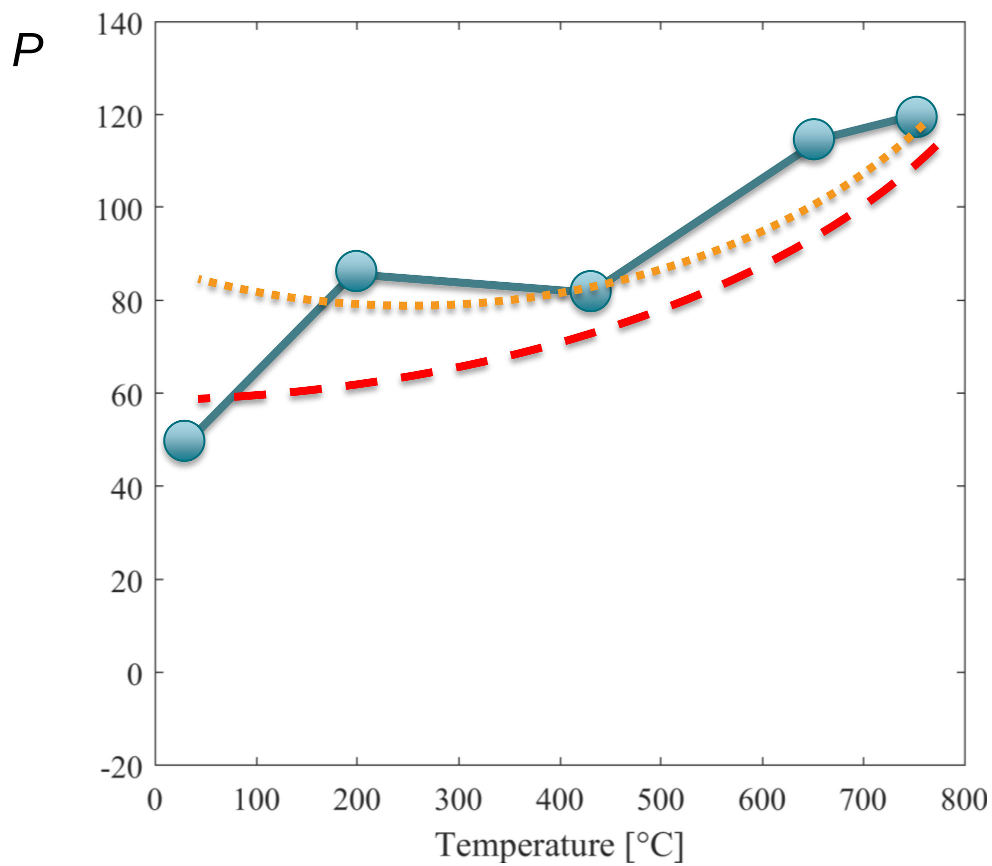
Barrett, P. R., Ahmed, R., Menon, M, Hassan, T., International Journal of Solids and Structures, 88–89, pp. 146–164, 2016



Temperature dependence

3rd method: Double exponential

$$P = A_P\left(1 - B_p \exp\left(\frac{T}{C_P}\right)\right) + A_P\left(1 - D_p \exp\left(\frac{T}{E_P}\right)\right)$$



→ 40 x 5 parameters (=200)

Temperature dependence

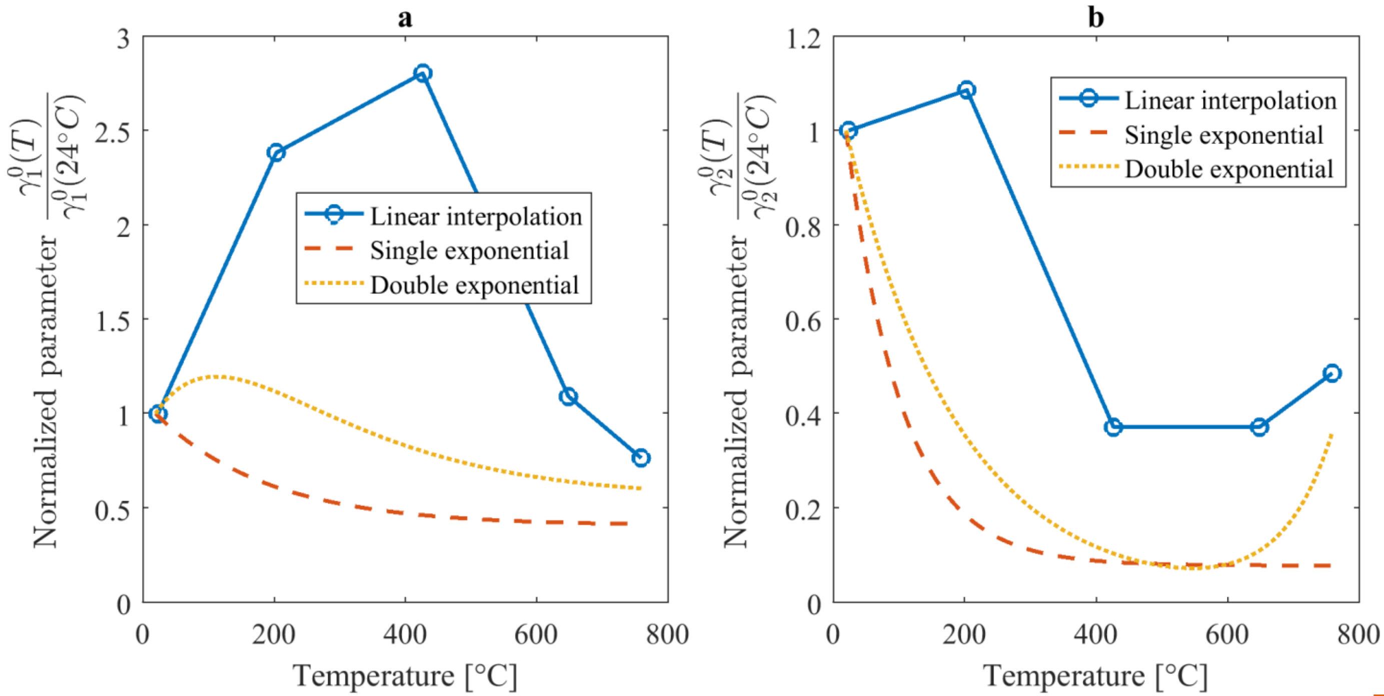
3rd method: Double exponential

$$P = A_P\left(1 - B_p \exp\left(\frac{T}{C_P}\right)\right) + A_P\left(1 - D_p \exp\left(\frac{T}{E_P}\right)\right)$$

Cyclic hardening

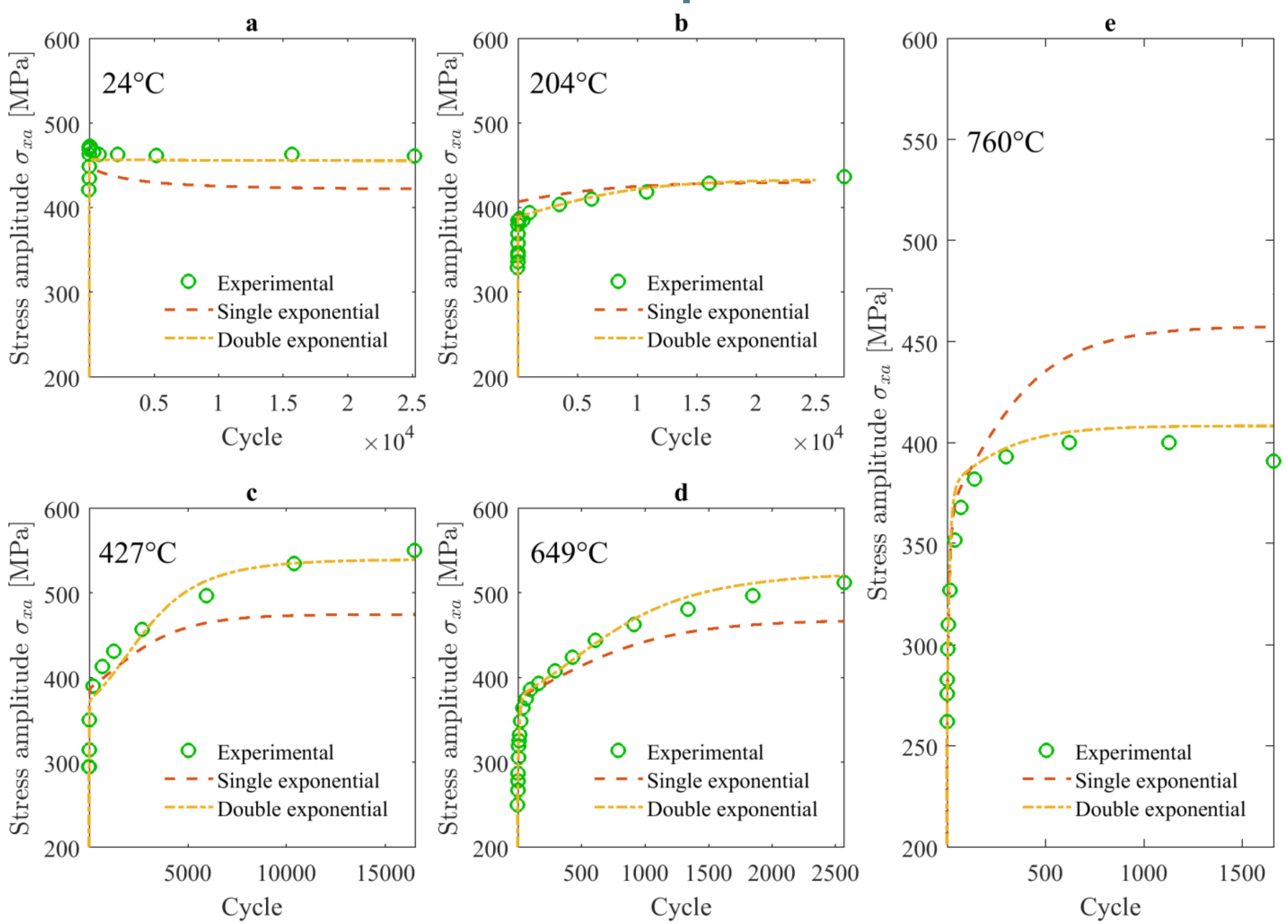
$$\dot{\gamma}_i = D_{\gamma i}(\gamma_i^0 - \gamma_i)\dot{p}$$

$$\gamma_i^0 = a_{\gamma i} + b_{\gamma i} e^{-c_{\gamma i} q}$$



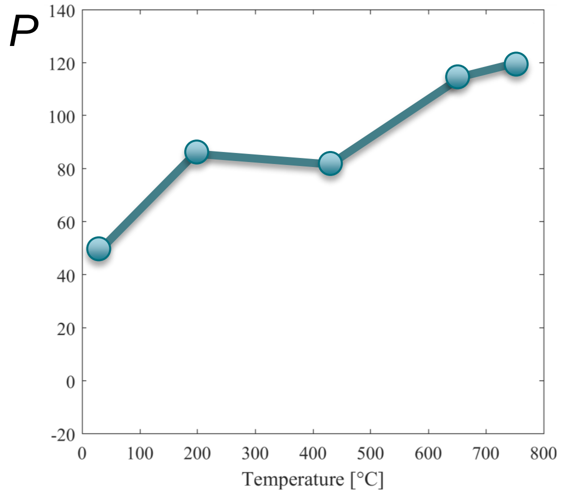
Temperature dependence

3rd method: Double exponential



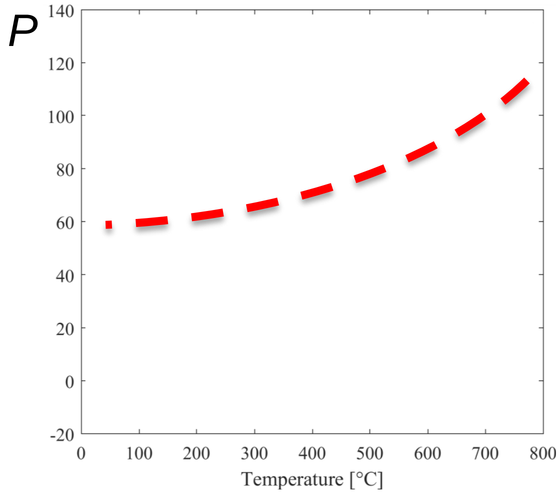
Conclusions

Multi-linear



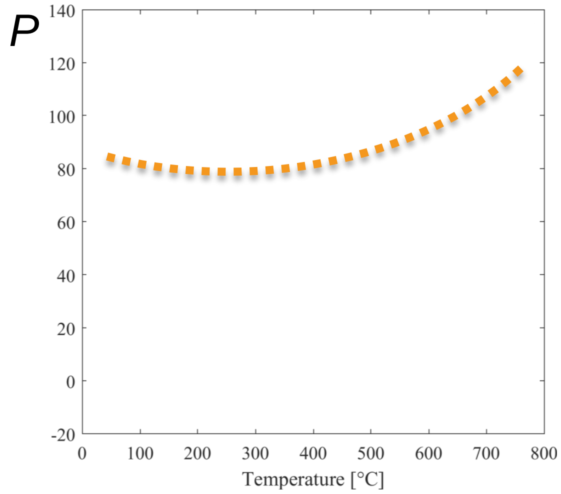
- Lack of continuity
- 40 x 5 parameters (=200)

Single exponential



- Only monotonic
- 40 x 3 parameters (=120)

Double exponential



- Good accuracy
- 40 x 5 parameters (=200)

LIÈGE université
Sciences Appliquées

UEE
Urban & Environmental Engineering

Modèle de base

$$\underline{\varepsilon} = \underline{\varepsilon}^{él} + \underline{\varepsilon}^{vp} + \underline{\varepsilon}^{th}$$

$$\underline{\sigma} = \underline{\underline{E}} : \underline{\varepsilon}^{él}$$

$$\dot{\underline{\sigma}} = \underline{\underline{E}} : \dot{\underline{\varepsilon}}^{él} + \dot{\underline{\underline{E}}} : \underline{\varepsilon}^{él}$$

Surface de plasticité

$$f = \|\underline{\sigma} - \underline{X}\| - \sigma_0 - R \leq 0$$

Contrainte visqueuse

$$\sigma_v = f > 0$$

Loi de viscosité

$$\dot{p} = \left\langle \frac{\sigma_v}{K} \right\rangle^n$$

$$Avec : \dot{p} = \sqrt{\frac{2}{3}\underline{\varepsilon}^{vp} : \underline{\varepsilon}^{vp}}$$

Ecrouissage cinématique

$$\hat{\underline{X}} = \sum_{i=1}^{nAF} \hat{\underline{X}}_i$$

$$\dot{\hat{\underline{X}}}_i = \frac{2}{3} C_i \dot{\underline{\varepsilon}}^{vp} - \gamma_i (\hat{\underline{X}}_i - \underline{Y}_i)\dot{p}$$

Restauration statique

$$\dot{\hat{\underline{X}}}_i = \ldots - b_i \|\underline{X}_i\|^{r_i - 1} \hat{\underline{X}}_i$$

Variations de température

$$\dot{\hat{\underline{X}}}_i = \ldots + \frac{1}{C_i}\frac{\partial C_i}{\partial T}\dot{T}\hat{\underline{X}}_i$$

Evolution de la contrainte moyenne

$$\dot{\underline{Y}}_i = -\alpha_{b,i}\left(\frac{3}{2}Y_{st,i}\frac{\hat{\underline{X}}_i}{\|\underline{X}_i\|} + \underline{Y}_i\right)\|\underline{X}_i\|^{r_i}$$

Ecrouissage cyclique

$$\dot{\gamma}_i = D_{\gamma i}(\gamma_i^0 - \gamma_i)\dot{p}$$

$$\gamma_i^0 = a_{\gamma i} + b_{\gamma i} e^{-c_{\gamma i} q}$$

Ecrouissage isotrope

$$\dot{R} = b(Q - R)\dot{p}$$

Influence de la température maximale

Influence sur l'écrouissage cyclique

$$\dot{D}_{\gamma i} = b_{D\gamma}(D_{\gamma i}^{T\max} - D_{\gamma i})\dot{p}$$

Evolution du module d'Young

$$E = f_E E + (1 - f_E) E_{T\max}$$

$$\dot{f}_E = b_E (f_E^S - f_E)\dot{p}$$